

Drag Characteristics of a Pickup Truck according to the Bed Geometry

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Abstract: The bed of a pickup truck is the most important part for the aerodynamic performance. The drag characteristics of the pickup truck were examined experimentally according to the bed geometry which was the variation of the bed length and the bed height with three levels. The experiments were conducted at the low turbulence wind tunnel of the close type. The mean drag coefficients of the model were measured by a load cell varying in the yaw angle up to fifteen degrees. The flow field around the tailgate was visualized by the PIV (Particle Image Velocimetry) method and the surface flow on the upper part of the tailgate and sidewalls were visualized by the oil-paint method. The drag coefficients distribution was ascent or descent tendency according to the bed geometry, which showed that the bed length and the bed height were related closely to the flow characteristics. The bed height was the dominant factor for the short bed, while the reverse flow in wake was dominant for the long bed. The occurrence and the size of the reverse flow in wake are dependent upon the bed geometry. For the low drag pickup truck, the recirculating flow inside the bed and the reverse flow in wake should be considered at the same time.

Key-Words: pickup truck, bed, drag, recirculating flow, side flow, wake, wind tunnel, PIV, oil visualization

1 Introduction

One of the hottest issues in the auto industry is the fuel economy because of the rising fuel price and the global warming problem. Aerodynamic approach is also important part to improve the vehicle's fuel efficiency so that there are so many aerodynamic researches for the drag reduction of a passenger car, a heavy truck, and a bus. Browand et al.[1] showed that drag reduction by adding base flaps saved the fuel of 1.63 liters per 100 km for the heavy truck-trailer. Roy et al.[2] simulated the three-dimensional flow over a simplified tractor-trailer geometry, and compared the numerical results to the experimental data. Kowata et al.[3] examined experimentally the drag reduction of the bluff-body by slanting the rear underbody and adding rear flaps to the rear-end. Howell et al.[4] tested a full scale compact SUV in the wind tunnel and on the test track, and established the correlation between the wind tunnel and on-road aerodynamic drag data by the coastdown technique.

Although a pickup truck is one of the most popular vehicle types today, there are only a few researches about the flow field around the pickup truck. It is just understanding the flow characteristics

around the pickup truck or validating CFD results with the experiment. Al-Garni et al.[5] presented the experimental data set of the flow structure in the near wake region of a generic pickup truck. They found the recirculating region over the bed bounded by the cab shear layer and no recirculating flow region behind a tailgate at the symmetry plane. Yang et al.[6], Lokhande et al.[7], Holloway et al.[8] analyzed numerically the flow characteristics of a pickup truck, and reported that the CFD data was matched well with experimental results. Mohkhtar et al.[9] investigated computationally the flow structure around four configurations of a pickup truck, and studied their influences on aerodynamic drag. Cooper [10] examined the aerodynamic effects of the tailgate, and resulted that the removal or the lowering of the tailgate increased the drag force.

From the previous studies, it is found that the bed behind the cabin plays an important role in the aerodynamic performance. But they did not deal with effect of the variation of the bed geometry. In this study, we examine the change of the flow characteristics of a pickup truck according to the bed geometry varying in the bed length and the bed height.

The drag coefficients distribution with the cross wind is investigated, and the flow mechanism around the bed is analyzed by the PIV method and the oil visualization through a series of the wind tunnel experiments.

2 Experimental Setup

2.1 Model Description

Figure 1 shows the pickup truck model, 1/10th scaled of the ordinary pickup truck, with an overall length of 528.6 mm, a height of 167.0 mm, and a width of 183.5 mm. Three levels of the bed length (L_B), and the bed height (H_B) were prepared for the variation of the bed geometry, as shown in Table 1. The baseline was the second level. The bed length and the bed height were normalized by the height of the cabin back (H).

2.2 Wind Tunnel Setup

The wind tunnel experiments were carried out at the open-jet low turbulence wind tunnel of the close return type (Göttingen type). The exit of the diffuser was the octagon shape whose subtense length was 293 mm. In order to substitute the ground, the fixed ground board was installed in the test section, as shown in Figure 2. The model was located 280 mm from the exit of the diffuser, and was supported on the ground board by four struts, which joined all wheels of the model to the supporting plate. The free stream velocity was 30 m/sec, and the Reynolds number was $Re = 1.03 \times 10^6$. The turbulence intensity was 0.4%, and the boundary layer thickness at the rear-end of the model was 10 mm. For the cross wind, the model was rotated counter-clockwise direction up to 15 degrees.

2.3 Measurements Methods

The mean drag coefficient was measured by a load cell at a rate of 1,000 Hz for 100 seconds, and its estimated uncertainty was less than 0.2%. The surface flows on the upper part of the tailgate and sidewalls, as shown in Figure 3, were visualized by the oil, a mixture of liquid paraffin and titanium dioxide (TiO_2). The flow field at the symmetry plane ($y = 0$ plane) around the tailgate, as shown in Figure 3, were visualized by the particle image velocimetry (PIV) method. The PIV camera took 350 photo pairs with the spatial resolution of $1,000 \times 1,016$ pixels and the time gap between laser pulses was 25 μ s. The velocity vectors which consisted of 50×50 grids were computed by the two frame cross correlation method.

Table 1 Bed geometry

| | Level 1 | Level 2 | Level 3 |
|----------------------|---------------------|------------------|------------------|
| Bed Length (L_B) | 1.62H (175.2 mm) | 1.92H (204.7) | 2.22H (233.4) |
| Bed Height (H_B) | 0.27H (26.2 mm) | 0.47H (45.7) | 0.67H (65.0) |

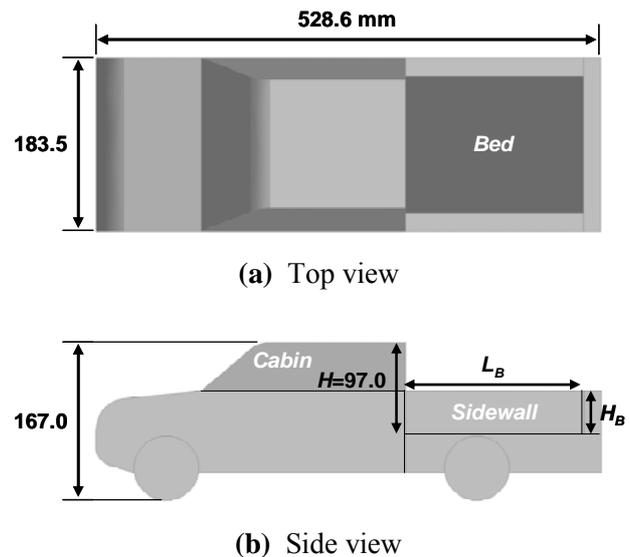


Figure 1 Pickup truck model

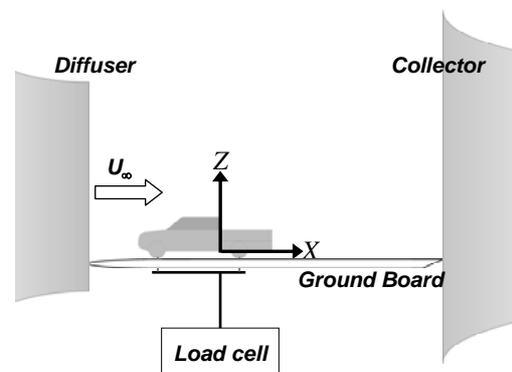


Figure 2 Wind tunnel setup

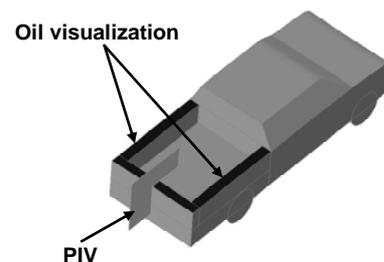


Figure 3 Measuring area of the PIV and the oil visualization

3 Experimental Results

Figure 4, the drag coefficients (C_D) distribution as a contour plot, shows the qualitative variation of the drag coefficient at zero yaw degree ($\psi = 0$ deg.). For the short bed ($L_B = 1.62H$), as the bed height was higher, the drag coefficient decreased, and vice versa for the long bed ($L_B = 2.22H$). Likewise, as the bed length was longer, the drag coefficient decreased for the low bed ($H_B = 0.27H$), and vice versa for the high bed ($H_B = 0.67H$). The bed length and the bed height were related closely to the drag characteristics.

The drag coefficient was the highest for the short and low bed ($L_B = 1.62H$, $H_B = 0.27H$). In this geometry, the flow over the bed, named as the bed flow, hit directly the upper part of the tailgate, as shown in Figure 5, which indicated that the bed flow was separated on the tailgate and maximized the recirculating flow inside the bed. This phenomenon is also shown in Figure 6, the oil visualization on the upper part of the tailgate and sidewalls. It can be seen that the side flows from the right and left cabin side flowed into the bed. Then, the side flows were mixed together with the bed flow, which was the recirculating flow inside the bed. Due to the existence of the tailgate at the position of flow mixing, however, the bed flow was separated on the tailgate. After that, some flowed into wake, and some into the bed as the recirculating flow inside the bed. Thus the drag coefficient became higher. In wake, the bed flow ran along the outside of the tailgate without the reverse flow.

Contrary to the low bed ($H_B = 0.27H$), the bed flow of the short and high bed ($L_B = 1.62H$, $H_B = 0.67H$) made the recirculating flow inside the bed without separation, and flowed along the upper part of the tailgate, as shown in Figure 7. Thus the recirculating flow inside the bed and the separation of the bed flow on the tailgate were affected by the bed height. The surface flow pattern on the tailgate also shows that the flow on the tailgate was not separated and flowed away into wake, as shown in Figure 8. The inflow of the side flow for the high bed was lesser than the low bed. The high sidewalls prevented the side flows from entering and mixing together inside the bed, which made the drag coefficient the lowest. Unlike the low bed, the reverse flow in wake was appeared for the high bed as a form of the wake flow for the bluff-body [11] [12]. However, this reverse flow in wake was not shown in the Al-Garni's result [5]. Therefore, the occurrence of the reverse flow behind the tailgate in wake is dependent upon the bed geometry. Accordingly, the recirculating flow inside the bed is more influential than the reverse flow in wake for the short bed.

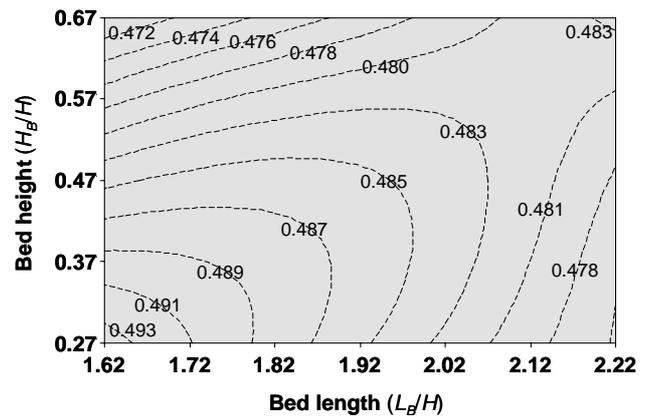


Figure 4 C_D distribution ($\psi = 0$ deg.)

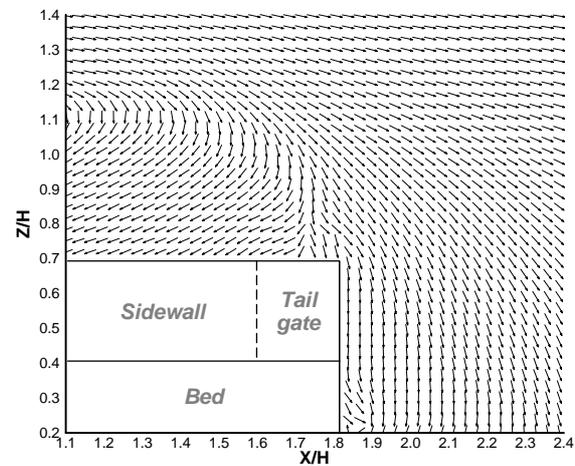


Figure 5 Velocity vectors around the tailgate (Bed length $1.62H$, Bed height $0.27H$)

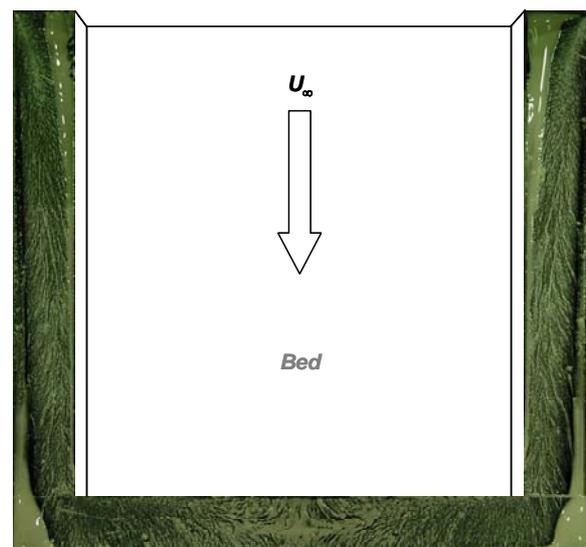


Figure 6 Oil visualization on the tailgate and sidewalls (Bed length $1.62H$, Bed height $0.27H$)

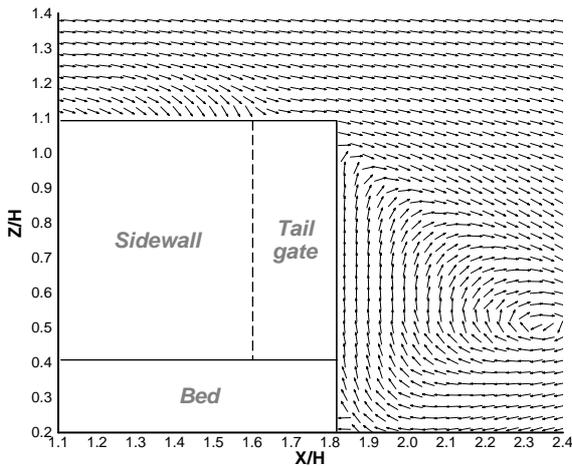


Figure 7 Velocity vectors around the tailgate (Bed length $1.62H$, Bed height $0.67H$)

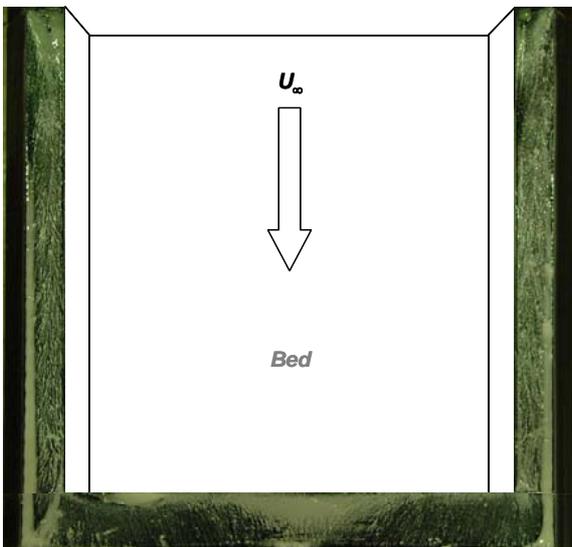


Figure 8 Oil visualization on the tailgate and sidewalls (Bed length $1.62H$, Bed height $0.67H$)

The drag characteristics, however, was changed oppositely for the long bed ($L_B = 2.22H$), as shown in Figure 4. The drag coefficient became to increase as the bed height was higher. In case of the long with low bed ($L_B = 2.22H$, $H_B = 0.27H$), the bed flow ran along the upper part of the tailgate and made the small reverse flow in wake, as shown in Figure 9 and 10, which was one of the biggest difference characteristics with the flow of the short bed. The downwash of the recirculating flow inside the bed fell into the inside of the tailgate, because the tailgate was placed further backward as the bed became longer.

Although the bed flow of the long with high bed ($L_B = 2.22H$, $H_B = 0.67H$) also flowed along the upper part

of the tailgate, as shown in Figure 11, the drag coefficient was slightly high. Since the surface flow on the tailgate and sidewalls were disturbed and the size of the reverse flow in wake was grown more, as shown in Figure 12. From the little drag coefficient variation for the long bed, as shown in Figure 4, the effect of the recirculating flow inside the bed was not dominant as much as the short bed. On the other hand, the reverse flow in wake became influential relatively.

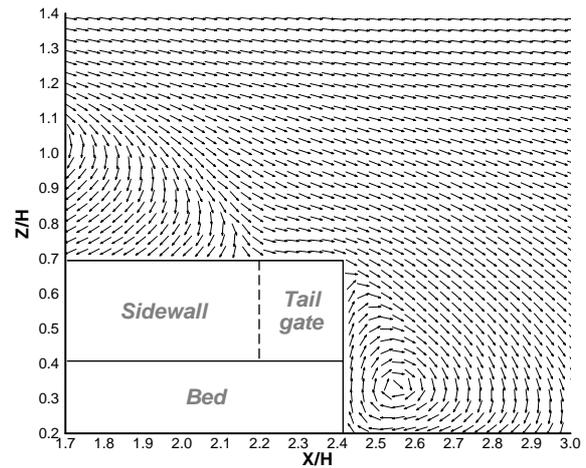


Figure 9 Velocity vectors around the tailgate (Bed length $2.22H$, Bed height $0.27H$)

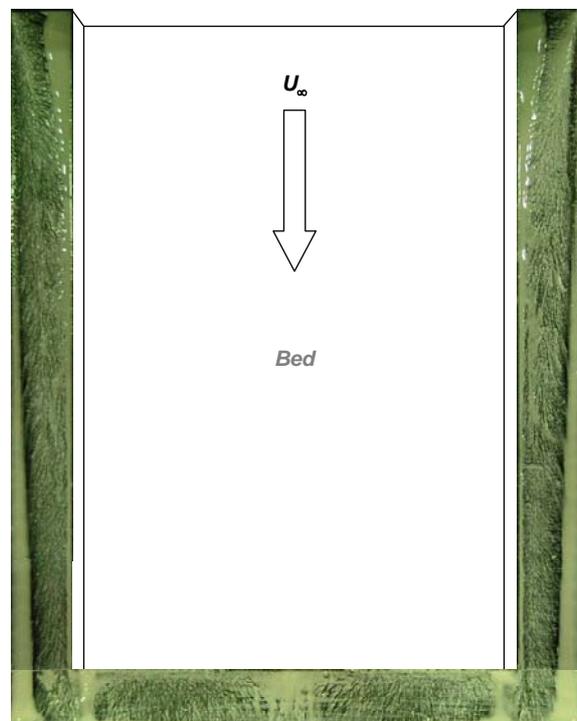


Figure 10 Oil visualization on the tailgate and sidewalls (Bed length $2.22H$, Bed height $0.27H$)

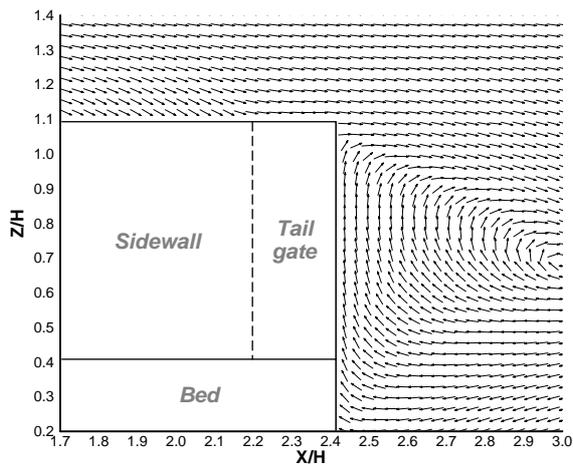


Figure 11 Velocity vectors around the tailgate (Bed length $2.22H$, Bed height $0.67H$)

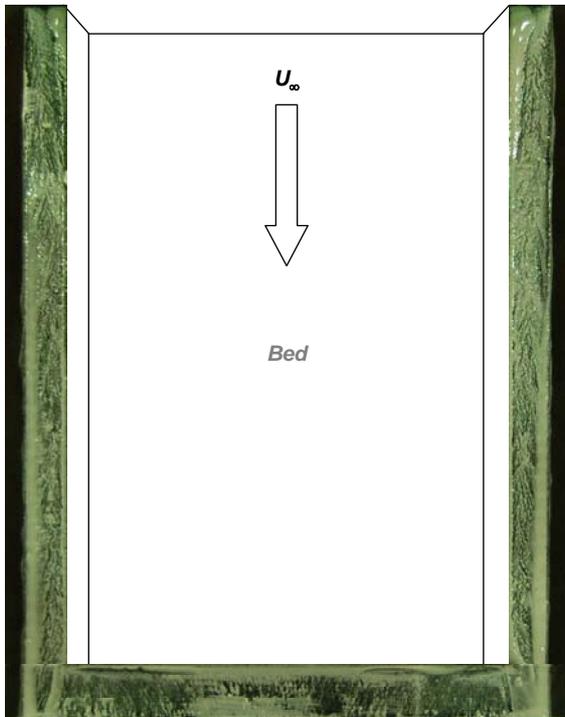


Figure 12 Oil visualization on the tailgate and sidewalls (Bed length $2.22H$, Bed height $0.67H$)

The drag coefficients distribution at 15 yaw degrees ($\psi = 15$ deg.) is shown in Figure 13. The contour plot shows that the longer bed or the higher bed led to the higher drag coefficient. Because the frontal projected area of the model was broadened for the cross wind. The drag coefficient of the short with low bed ($L_B = 1.62H$, $H_B = 0.27H$), however, was still rather high due to the effect of the separated bed flow on the tailgate.

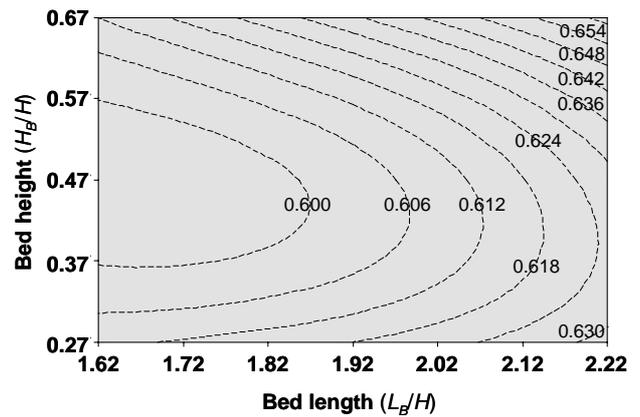


Figure 13 C_D distribution ($\psi = 15$ deg.)

4 Conclusions

The drag characteristics of the pickup truck were examined experimentally. The drag coefficients distribution at zero yaw angle was the ascent or descent tendency according to the bed geometry. The bed length and the bed height were related closely to the flow characteristics. In case of the short with low bed, the drag coefficient was rather high because of the separated bed flow on the tailgate, regardless of the cross wind. As the bed height was higher, the bed flow ran along the upper part of the tailgate, and the drag coefficient became lowered. Thus the bed height is dominant for the short bed. On the other hand, the reverse flow in wake became more influential to the flow characteristics for the long bed relatively. The occurrence and the size of the reverse flow in wake are dependent upon the bed geometry. Another factor that affected to the drag coefficient was the side flow into the bed, so that the side flow also should be considered for low drag as well as the bed flow.

In conclusion, the recirculating flow inside the bed and the reverse flow in wake are having an effect on the flow characteristics at the same time. In order to create the low drag pickup truck, the bed flow on the tailgate should not be separated but should flow along the upper part of the tailgate, and the reverse flow in wake should be weak.

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